ORIGINAL ARTICLE

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Assessment of environmental tobacco smoke and respirable suspended particle exposures for nonsmokers in Prague using personal monitoring

Abstract *Objective:* Exposures to respirable suspended particles (RSP) and environmental tobacco smoke (ETS) were assessed in Prague, Czech Republic, to determine the range and degree of personal exposure by means of personal monitoring over a 24-h period. *Design:* Self-reported nonsmokers were randomly selected from a representative sample of the population of Prague. Housewives were recruited into one group, primarily for assessment exposures in the home, and office workers were recruited into a second group for assessment of the contribution from the workplace. *Methods:* A total of 238 randomly selected nonsmoking subjects collected air samples near their breathing zone by wearing personal monitors for 24 h. Samples collected were analyzed for RSP, nicotine, 3-ethenylpyridine, and ETS particles (using ultraviolet absorbance, fluorescence, and solanesol measurements). Saliva cotinine analyses were also undertaken to confirm the nonsmoking status of the subjects. *Results:* The most highly exposed subjects in this study were office workers both living and working with smokers. Median time-weighted average exposure concentrations of 60 $\mu g\ m^{-3}$ RSP, 16 $\mu g\ m^{-3}$ ETS particles, and 1.6 $\mu g\ m^{-3}$ nicotine were determined for these subjects, who also had the highest median saliva cotinine level of 2.4 ng ml^{-1}. Housewives living in nonsmoking households were the least exposed subjects in this study, showing levels of 32 $\mu g\ m^{-3}$ RSP, 0.17 $\mu g\ m^{-3}$ ETS particles, and 0.15 $\mu g\ m^{-3}$ nicotine. As based upon median levels of ETS particles and nicotine, no group would potentially inhale or be exposed to more than 10 cigarette equivalents per year (CE/y) and the least exposed would inhale less than 1 CE/y. The most highly exposed (90th percentile levels) nonsmokers in this study, who both worked and lived with smokers, would potentially inhale up to 29 CE/y. Overall, the workplace was estimated to contribute between 45% and 49% of the annual exposure to nicotine and ETS particles, respectively. On the basis of determined saliva cotinine concentrations, a misclassification rate of between 1.7% and 2.5% was calculated. *Conclusions:* Highest exposures were apparent for office workers both working and living in smoking environments, and our findings suggest a significant contribution to overall ETS particle and nicotine levels from the workplace where smoking takes place. Overall, the rates at which subjects were determined to have misclassified their smoking status in this study were the lowest observed in any of the European cities investigated to date. Clearly, a more sensitive method of analysis for cotinine in body fluids is needed for more accurate determination of the levels expected for nonsmokers.

Key words Personal exposure · Respirable suspended particles · Environmental tobacco smoke · Nicotine · Cotinine

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Introduction

Prague was the eighth successive major European city studied by these authors with regard to air quality, following on from investigations conducted in Stockholm (Phillips et al. 1996), Barcelona (Phillips et al. 1997a), Turin (Phillips et al. 1997b), Paris (Phillips et al. 1998a), Bremen (Phillips et al. 1998b), Lisbon (Phillips et al. 1998c) and Basel (Phillips et al. 1998d). Situated on the river Vltava in the heart of continental Europe, Prague is the capital of the newly formed Czech Republic and has a population of approximately 1.2 million.

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Personal monitoring was chosen for this study in preference to static or ambient measurements so as to obtain a more accurate representation of personal exposures to selected pollutants. The study involved subjects monitoring the air close to their breathing zone over 24-h periods in Prague, Czech Republic, during October/November 1995. Environmental tobacco smoke (ETS) particles were estimated using ultraviolet absorbing particulate matter (UVPM), fluorescing particulate matter (FPM) and solanesol-related particulate matter (SolPM). Vapour phase ETS exposures were also assessed by simultaneous measurement of nicotine and 3-ethenylpyridine (3-EP) concentrations. For the evaluation of exposures to ETS and respirable suspended particles (RSP), households and workplaces were classified as smoking or nonsmoking. Subjects also provided saliva samples for cotinine analysis and self-reported activities using diaries and questionnaires. Similar methodologies have been used in other recent studies (Heavner et al. 1996; Jenkins et al. 1996; Sterling et al. 1996; Baek et al. 1997).

The study was designed to assess the exposure of housewives and office workers to RSP and ETS particles by obtaining accurate measurements of air concentrations. The information collated herein should provide some meaningful data to allow informed and objective debate on issues related to passive smoking and exposures to RSP overall. The results should also provide the opportunity to compare and contrast a city from a former "Eastern Block" country with major cities in Central Europe. The main objectives of this study were:

1. To recruit random subjects, who were representative of the population of Prague, into six separate lifestyle "cells"
2. To determine the range and degree of personal exposure within these cells of selected subjects to RSP and ETS constituents by means of personal air sampling over a 24-h period
3. To assess the contribution of the workplace to overall ETS and RSP exposure

Methods

Recruitment of subjects

Recruitment was performed by GfK, a leading direct marketing company in the Czech Republic that possesses the most complete personal data base in the country. A representative population was selected from the data base to be compliant with the following criteria:

1. All subjects were to be nonsmokers living within 15 km of the Prague city centre.
2. Equal proportions were recruited from three age groups: 20-34, 35-49, and 50-64 years.
3. Subjects' life styles were to be representative of the population living within 15 km of the city centre.
4. Subjects were to be distributed between six "cells" as indicated in Table 1, cells 3-6 being targeted at office workers.

Table 1 Cell categorisation by home and workplace status (Prague)

| Cell | Study type | Smoking status | | Planned number |
		Household	Workplace	
1	Single monitor	Smoking	-	55
2	Single monitor	Nonsmoking	-	40
3	Dual monitor	Smoking	Smoking	45
4	Dual monitor	Smoking	Nonsmoking	30
5	Dual monitor	Nonsmoking	Smoking	40
6	Dual monitor	Nonsmoking	Nonsmoking	30

Subjects were recruited from this representative population using randomly selected telephone numbers and were screened to confirm their eligibility to participate in the study. Suitable volunteers were given an appointment to attend an information/training session organised either at the Renaissance Prague Hotel or at the Hotel Hilton Atrium, also in Prague.

For the assignment of subjects into cells as depicted in Table 1, households were classified as "smoking" if a smoker of cigarettes, pipes or cigars was resident and also normally smoked within communal areas of the household. The smoking status of a workplace was defined by the absence/presence of smoking co-workers within 30 m of the subject's workstation. These definitions were chosen for the best representation of "real world" situations and for consistency across the different cities under study, where the attitudes of residents may vary considerably from country to country. The regulations governing air quality in the workplace were also different in each country at the time the studies were undertaken.

Monitoring session

Subjects were required to wear a personal monitor designed to collect particulate and vapour phase components present in the air close to the subject's breathing zone (Ogden et al. 1996). RSP and ETS particles were collected onto a Fluoropore membrane filter, and nicotine and 3-EP were adsorbed onto XAD-4 resin beads. The personal monitoring methodology has been described in detail elsewhere (Phillips et al. 1996) and is briefly described below.

First visit to the study centre

On arrival, subjects were shown an instructional video, dubbed into Czech, explaining the objectives of the air quality survey and were given further instructions regarding use of the equipment and completion of the documentation by locally recruited interpreters. Subjects were issued Czech language questionnaires and diaries for recording of exposures and observations over the 24-h collection period and were supervised during completion of a "first visit" questionnaire. For avoidance of misinterpretation and possible errors in translation, all questionnaires and diaries were designed for either numeric or tick-box answers. Nonworking subjects recruited for participation in cells 1 and 2 were provided with a single personal monitor for use over the collection period (single monitor study). Working subjects recruited for participation in cells 3-6 were provided with two personal monitors for use over the same period (dual monitor study). All subjects were required to provide a saliva sample prior to the monitoring period (pre-sample).

Last visit to the study centre

Following completion of the 24-h monitoring period, subjects returned their personal monitors and associated documentation to the study centre. Subjects also provided a second saliva sample (post-sample) and completed a "last visit" questionnaire.

Table 2 Limits of quantification (LOQ) for the analytical methods (Prague)

Measurement[a]	Analytical LOQ	LOQ expressed as an air concentration according to sampling time (μg m^{-3})[b]			Proportion of data below the LOQ
		24 h	15.7 h[c]	7.85 h[d]	
RSP	15.8 µg/filter	6.4	9.7	19	6%
UVPM	1.28 µg/filter	0.51	0.79	1.6	0
FPM	0.30 µg/filter	0.12	0.19	0.37	0
SolPM	0.84 µg/filter	0.34	0.52	1.0	28%
Nicotine	0.1 µg/tube	0.09	0.13	0.27	28%
3-Ethenylpyridine	0.1 µg/tube	0.09	0.13	0.27	39%
Saliva cotinine	1.0 ng ml^{-1}	–	–	–	44%

[a] RSP: Respirable suspended particles, UVPM: environmental tobacco smoke (ETS) particles estimated by ultraviolet absorption, FPM: ETS particles estimated by fluorescence, SolPM: ETS particles estimated by solanesol content
[b] A flow rate of 1.72 l min^{-1} through the Fluoropore filter was assumed in the LOQ calculation for RSP, UVPM, FPM and SolPM. The LOQ calculation for nicotine and 3-ethenylpyridine assumed a flow rate of 0.8 l min^{-1} through the XAD-4 tube
[c] Mean time spent outside the workplace for working subjects in Prague
[d] Mean time spent at work for working subjects in Prague

Analytical procedures

All analytical procedures were validated and have previously been fully described by these authors (Phillips et al. 1996). In this study the following analytes were determined:

1. RSP – using a gravimetric procedure (Ogden et al. 1990).
2. Saliva cotinine – using a radioimmunoassay procedure (Van Vunakis et al. 1987; Davis and Stiles 1993).
3. Nicotine and 3-EP – using a capillary gas chromatography (GC) procedure with nitrogen-specific detection (Ogden et al. 1989).
4. Estimation of ETS particles (three procedures) – using high-performance liquid chromatography (HPLC) procedures to determine the ultraviolet absorbance (UVPM), fluorescence (FPM) or solanesol content (SolPM) of methanolic filter extracts (Ogden et al. 1990; Phillips et al. 1996). The factors used in this study to convert instrument responses into an equivalent concentration of ETS particles were 56 (SolPM), 47 (FPM) and 8.5 (UVPM) as determined by Nelson et al. (1997).

The analytical limits of quantification (LOQ) for these analyses are presented in Table 2 together with the proportion of data below the LOQ. For the calculation of summary statistics any finding below the analytical LOQ was assigned a value of 1/2LOQ prior to calculation of the exposure concentration using the appropriate air sampling volume. The LOQs expressed as air concentrations in Table 2 are therefore only approximations, as they varied for each sample, depending upon the sampling-pump flow rate and monitoring time.

Subject selection

Of the 248 subjects initially recruited for the study, 2 were excluded because they failed to collect their samples correctly, 2 were excluded after having admitted to being a smoker during the initial visit to the study centre and 4 were excluded because their saliva cotinine levels were above the selected threshold (25 ng ml^{-1}) for nonsmokers. A further 2 subjects were excluded due to the absence of saliva cotinine data required to confirm nonsmoking status.

The age and sex distributions of the remaining 238 subjects who successfully completed the study are presented in Table 3. In the single monitor study, over half of the recruited housewives were aged below 35 years, a somewhat higher proportion than the planned 33%. Also apparent was a considerable over-representation of female workers in the dual monitor study from the planned 50% per sex (70% female versus 30% male). There was also an over-representation of the 35- to 49-year age group from the planned 33% in the dual monitor study, probably reflecting the age distribution of office workers in Prague. The employed participants were questioned about their occupation on the first visit questionnaire and were restricted to a choice of 13 options from which to select and provide their answers. Of the 144 subjects who responded to this question, 75 worked in administrative/secretarial positions, whilst another 45 subjects were employed almost equally between engineering, government agencies, legal/financial, wholesale/retail and science/computing.

Table 3 Age and sex distribution for study subjects (Prague)

Subject group[a]	Sex		Age range (years)				Overall total
	Males	Females	20–34	35–49	50–64	> 64	
Cell 1		54	36	7	10	1	54
Cell 2		39	17	4	18		39
Cell 3	21	43	15	33	16		64
Cell 4	2	11	6	5	2		13
Cell 5	15	33	12	20	16		48
Cell 6	5	15	3	13	4		20
Single monitor total		93	53	11	28	1	93
Dual monitor total	43	102	36	71	38		145
Overall total	43	195	89	82	66	1	238

[a] Cell 1: smoking household, cell 2: nonsmoking household, cell 3: smoking household/smoking workplace, cell 4: smoking household/nonsmoking workplace, cell 5: nonsmoking household/smoking workplace, cell 6: nonsmoking household/nonsmoking workplace

During recruitment it was apparent that smoking was allowed in the majority of office environments; hence, recruitment of the planned number of working subjects into cells consisting of non-smoking workplaces proved to be unachievable. As compensation for this shortfall and for a closer reflection of the city's population, cells comprising a smoking workplace were over-recruited as compared with their original planned totals.

For a subject to be assigned to a particular cell, procedures must be defined to classify the household and/or workplace as "smoking" or "nonsmoking". In a recent United States study, using a protocol similar to that used in their European studies, Jenkins et al. (1996) reported data based on two separate procedures. Initially, subjects were assigned to a cell on the basis of their responses to the telephone screening questionnaire; cell categorisations were subsequently refined by rejection of subjects whose diary observations did not correspond to their initial cell assignments.

In this study, neither of the above-mentioned procedures were utilised; instead, cells were categorised according to the answers provided on the first visit questionnaire. It was believed that responses to the screening questionnaire could not always be guaranteed due to the possible incorrect categorisation of cells by telephonists working for the recruitment agencies. It was noted on the pump survey questionnaires that 47% of subjects admitted to incomplete recording of diary observations throughout the monitoring period; thus, the use of diary observations to refine cell categorisation was not considered.

Results and discussion

Smoking status and misclassification

Saliva cotinine levels were determined to verify that recruited subjects had correctly reported themselves as nonsmokers. Various threshold levels, above which subjects would be classified as smokers, have been suggested and include 10 ng ml^{-1} (Etzel 1990), 15 ng ml^{-1} (McNeill et al. 1987), 30 ng ml^{-1} (Lee 1987) and, more recently, 100 ng ml^{-1} (Sterling et al. 1996). In this study, 25 ng ml^{-1} (maximum of pre- and post-levels) was chosen as a suitable cut-off level as used and described previously by these authors (Phillips et al. 1994). With the use of this threshold, four subjects with levels ranging between 36.3 and 259 ng ml^{-1} were assumed to be smokers and were excluded from the study. Etzel's review (1990) of the use of saliva cotinine for this purpose suggests that subjects with cotinine levels of between 10 and 100 ng ml^{-1} may be classified as infrequent smokers, and had 10 ng ml^{-1} been selected as the cut-off level in this study, a further 4 subjects would have been rejected. In a nationally representative study of married females in the United States, Ogden et al. (1997) could have rejected 64 of 699 (9.2%) self-reported nonsmokers using a threshold of 10 ng ml^{-1} and 33 of 699 (4.7%) using a threshold of 106 ng ml^{-1}.

In this study, subjects were required to confirm that they had been nonsmokers for more than 6 months and no attempt was made to differentiate between "non" and "never" smokers. Various criteria can be used to assess the rate at which recruited subjects misreport their smoking status, including responses to questionnaires. In addition to those subjects who were rejected due to elevated saliva cotinine levels, two subjects were excluded from the study after admitting to being smokers on the first visit questionnaire and a further two were excluded since cotinine data for these subjects were not available to confirm nonsmoking status. Depending upon the criteria used, the rate at which subjects misclassified their smoking status in this study ranged between 1.7% (4 of 242) and 2.5% (6 of 244). Overall, these misclassification rates were the lowest observed in any of the European cities studied to date by these authors. There does not appear to be any obvious reason why Prague should have the lowest rate. It is possible that "smoking" or being a "smoker" in Prague at the time of these studies was socially more acceptable than in some of the other cities studied. Therefore, there may have been no stigma attached to being a smoker and less reason to conceal a true smoking status.

Comparison of "markers" for estimation of ETS concentrations

Table 4 lists the correlation and best-fit line coefficients between various analytes measured in this study after the removal of data pairs where either analyte was below the LOQ. The correlation of SolPM with nicotine is depicted as a scatter diagram in Fig. 1. The cumulative frequency distributions determined for particulate matter estimates using 24-h time-weighted average (TWA) concentrations are shown in Fig. 2. The expected ranking of RSP > UVPM > FPM > SolPM is not depicted in these distributions, in contrast to the other European cities studied by these authors, where this trend was observed.

Examination of Table 4 shows good correlation between ETS particle estimates obtained using the SolPM and UVPM methods ($R^2 = 0.80$) and a moderate correlation between SolPM and FPM estimates ($R^2 = 0.63$). A moderate correlation between FPM and UVPM estimates ($R^2 = 0.78$) was also apparent, although this is not surprising since the majority of determined FPM particles will also be detected by UVPM methodology. A poor correlation was found for both SolPM and FPM with nicotine, possibly reflecting the different behavioural characteristics of vapour and particulate phases of ETS. In contrast, the correlation of the vapour phase components nicotine and 3-EP was good, with a gradient suggesting that nicotine concentrations were approximately 3 times higher than 3-EP levels. Determined R^2 values of approximately 0.8 (Table 4) were similar to those found between particulate phase ETS markers. There was also an indication from Table 4 that ETS particle concentrations correlated better with nicotine than with 3-EP, possibly due to the higher number of 3-EP measurements close to the LOQ, where acceptable assay reliability will be at a minimum.

Post-cotinine concentrations did not correlate with the corresponding nicotine, SolPM or FPM values. In this study, cotinine levels were intended to be used only for distinguishing smokers from nonsmokers. At the time of this study, no literature methods were available

Table 4 Correlation coefficients for ETS "markers" using only data greater than the LOQ (Prague)

"Y" data vs	"X" data	Data pairs	R^2	Gradient	Intercept
FPM	UVPM	337	0.780	0.792	11.35
SolPM	UVPM	243	0.795	0.790	−10.31
SolPM	FPM	246	0.625	0.811	−13.09
3-EP	Nicotine	212	0.824	0.269	0.280
FPM	Nicotine	229	0.389	10.265	33.63
SolPM	Nicotine	201	0.276	8.884	14.29
UVPM	Nicotine	225	0.441	12.636	24.36
SolPM	3-EP	168	0.106	7.300	33.71
FPM	3-EP	188	0.079	6.123	55.45
Post-cotinine	Nicotine[a]	85	0.000	0.010	3.09
Post-cotinine	SolPM[a]	81	0.001	−0.002	3.20
Post-cotinine	FPM[a]	113	0.004	0.004	2.67

[a] Time-weighted average concentrations used for working subjects (cells 3–6) having results from both the "workplace" and "outside of the workplace" monitors greater than the LOQ

with an LOQ below 0.5 ng ml^{-1}, an essential requirement for comparison of cotinine levels amongst non-smokers. This lack of correlation was observed by these authors in previous studies and indicates that the use of cotinine as a biomarker for ETS exposure could be misleading under certain conditions.

Concentrations of ETS constituents to which Prague subjects were exposed

In this publication, we primarily used median values to report RSP and ETS marker concentrations since the data generated were highly skewed. Additionally, arithmetic and geometric means were listed together with 10th and 90th percentile values for each data set. In addition, ETS particle concentrations. corresponding cigarette equivalent (CE) calculations and comparisons between subject groups and cells were based upon Sol-PM determinations, although FPM values were reported alongside for comparison. It has previously been suggested (Ogden et al. 1990) that SolPM and, to some extent, FPM methods are more specific to ETS particles
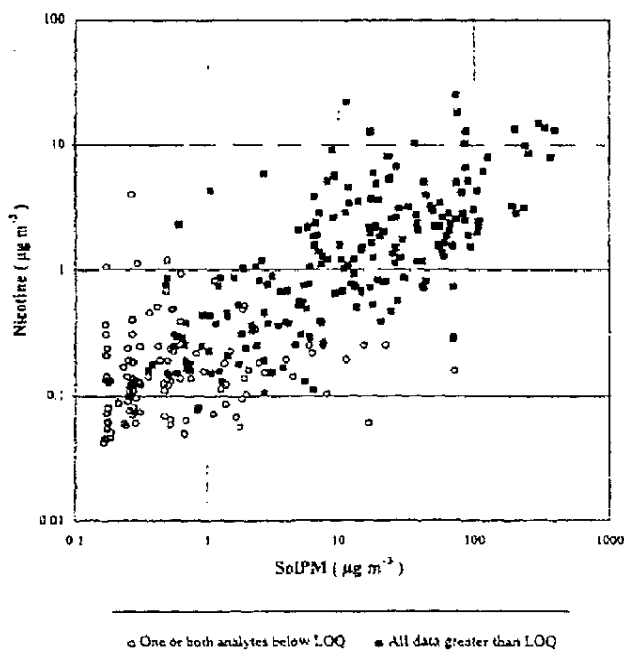

Fig. 1 Correlation of SolPM with nicotine (Prague)

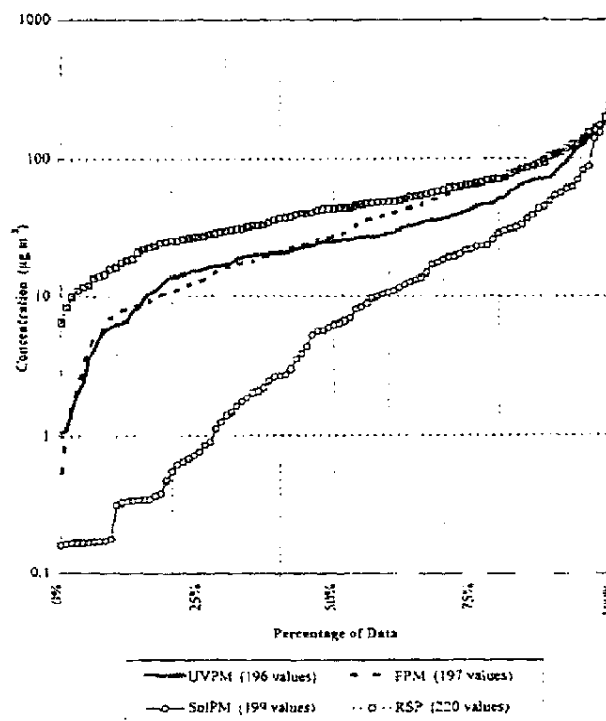o One or both analytes below LOQ   • All data greater than LOQ

Fig. 2 Cumulative frequency distributions of 24-h TWA particulate matter concentrations (Prague)

—— UVPM (196 values)   • - FPM (197 values)
—o— SolPM (199 values)   ··o·· RSP (220 values)

than the use of UVPM methods, which are sensitive to other combustion sources. The cumulative frequency distributions (Fig. 2) show that FPM values in general were greater than UVPM levels, and at higher levels they were equivalent to RSP values. These elevated FPM levels are likely to be attributable to a higher concentration of fluorescing compounds in the atmosphere emanating from sources such as industrial sites and coal-fired electricity generators. ETS particle concentrations based upon fluorescence measurements were therefore considered to have provided an over-estimate of ETS particle exposures.

Particulate and vapour phase components measured for housewives were compared, by cell, with calculated TWA concentrations for individual workers. These calculations were based on measured concentrations and the operational time over which the monitors were used inside and outside the workplace. These data are summarised in Tables 5 and 6. The cumulative frequency distributions determined for ETS particles (SolPM) by cell are shown in Fig. 3. The significance of any concentration differences between cells was examined using the Wilcoxon rank-sum test. Prior to the application of this nonparametric test. Kruskal-Wallis nonparametric analysis of variance (ANOVA) was applied to the data so as detect if there was an overall difference between the cells. If the overall Kruskal-Wallis analysis proved nonsignificant ($P > 0.05$), any

significance detected using the Wilcoxon rank-sum test would be considered to be a false-positive finding. For all the analytes investigated, the Kruskal-Wallis ANOVA provided evidence of a significant overall difference between cells and subsequent pairwise comparisons of cells were performed using the Wilcoxon rank-sum test.

The highest median 24-h RSP concentration in this study (60 μg m^{-3}) was found for workers living in smoking households and working in smoking workplaces (cell 3). In comparison, the median concentration previously reported for cell 3 subjects in Paris was 80 μg m^{-3} (Phillips et al. 1998a), and 39 μg m^{-3} was reported for corresponding subjects in Basel, Switzerland (Phillips et al. 1998d). The levels recorded in Prague for cell 3 subjects were not significantly different ($P > 0.05$) from those reported for housewives living in smoking households (cell 1; median 48 μg m^{-3}). The lowest median RSP concentrations were recorded for housewives living in nonsmoking households (cell 2; 32 μg m^{-3}) and for workers both living and working in nonsmoking environments (cell 6; 30 μg m^{-3}).

The highest median level for ETS particles (16 μg m^{-3}) was also determined for subjects in cell 3, this concentration representing approximately 27% of measured RSP. The equivalent levels in Paris and Basel were lower at 9.8 and 6.6 μg m^{-3}, respectively. The levels determined for this cell in Prague were signifi-

Table 5 Summary of 24-h TWA particle concentrations recorded for all subjects by cell (Prague)[a]

Analyte	Subject group[b]	Number of subjects	10th percentile	90th percentile	Arithmetic mean	Geometric mean	Median
	Cell 1	50	19	112	61	48	48
	Cell 2	36	11	55	35	28	32
RSP	Cell 3	56	28	130	72	61	60
(μg m^{-3})	Cell 4	12	23	52	49	39	40
	Cell 5	47	17	66	45	38	40
	Cell 6	19	14	66	56	30	30
	Cell 1	46	0.17	58	20	4.6	7.4
	Cell 2	19	0.17	5.3	5.7	0.49	0.17
SolPM	Cell 3	56	1.3	61	30	12	16
(μg m^{-3})	Cell 4	12	0.35	21	24	3.6	4.7
	Cell 5	47	0.35	47	20	5.6	6.1
	Cell 6	19	0.34	11	3.7	1.6	2.1
	Cell 1	46	7.8	103	57	37	49
	Cell 2	19	1.1	66	20	5.7	4.8
FPM	Cell 3	55	16	123	62	46	46
(μg m^{-3})	Cell 4	12	11	52	38	25	21
	Cell 5	46	9.7	60	35	25	24
	Cell 6	19	7.8	25	17	14	13
	Cell 1	46	6.3	72	39	26	28
	Cell 2	19	1.4	36	13	4.8	4.3
UVPM	Cell 3	55	18	116	55	42	42
(μg m^{-3})	Cell 4	12	10	27	37	23	21
	Cell 5	45	15	40	33	26	24
	Cell 6	19	10	26	18	16	16

[a] TWA exposure concentrations, determined for each subject from measured levels both inside and outside the workplace, were used to calculate the statistical parameters shown for cells 3-6
[b] Cell 1: smoking household, cell 2: nonsmoking household, cell 3: smoking household/smoking workplace, cell 4: smoking household/nonsmoking workplace, cell 5: nonsmoking household/smoking workplace, cell 6: nonsmoking household/nonsmoking workplace

Table 6 Cotinine and 24-h TWA nicotine and 3-EP concentrations recorded for all subjects by cell (Prague) (*3-EP* 3-Ethenylpyridine)

Analyte	Subject group[b]	Number of subjects	10th percentile	90th percentile	Arithmetic mean	Geometric mean	Median
Nicotine ($\mu g\ m^{-3}$)	Cell 1	51	0.13	3.1	1.3	0.63	0.72
	Cell 2	38	0.05	0.51	0.31	0.16	0.15
	Cell 3	57	0.37	4.9	2.3	1.5	1.6
	Cell 4	12	0.18	4.6	1.3	0.57	0.45
	Cell 5	45	0.13	2.2	1.1	0.54	0.49
	Cell 6	19	0.11	0.52	0.25	0.20	0.16
3-EP ($\mu g\ m^{-3}$)	Cell 1	51	0.08	1.5	0.52	0.30	0.26
	Cell 2	38	0.07	0.28	0.18	0.13	0.12
	Cell 3	57	0.24	1.7	0.91	0.67	0.77
	Cell 4	12	0.10	1.1	0.54	0.31	0.27
	Cell 5	46	0.10	0.90	0.67	0.31	0.29
	Cell 6	19	0.09	0.27	0.16	0.15	0.14
Cotinine[c] ($ng\ ml^{-3}$)	Cell 1	54	0.50	5.2	2.4	1.3	1.2
	Cell 2	39	0.50	1.6	0.98	0.69	0.50
	Cell 3	64	0.58	3.9	2.7	2.1	2.4
	Cell 4	13	0.80	3.0	1.9	1.6	1.8
	Cell 5	48	0.50	2.3	1.4	1.1	1.1
	Cell 6	20	0.50	1.2	0.71	0.61	0.50

[a] TWA exposure concentrations, determined for each subject from measured levels both inside and outside the workplace, were used to calculate the vapour phase statistical parameters shown for cells 3–6
[b] Cell 1: smoking household, cell 2: nonsmoking household, cell 3: smoking household/smoking workplace, cell 4: smoking household/nonsmoking workplace, cell 5: nonsmoking household/smoking workplace, cell 6: nonsmoking household/nonsmoking workplace
[c] Values were calculated from the average of pre- and post-monitoring saliva cotinine concentrations
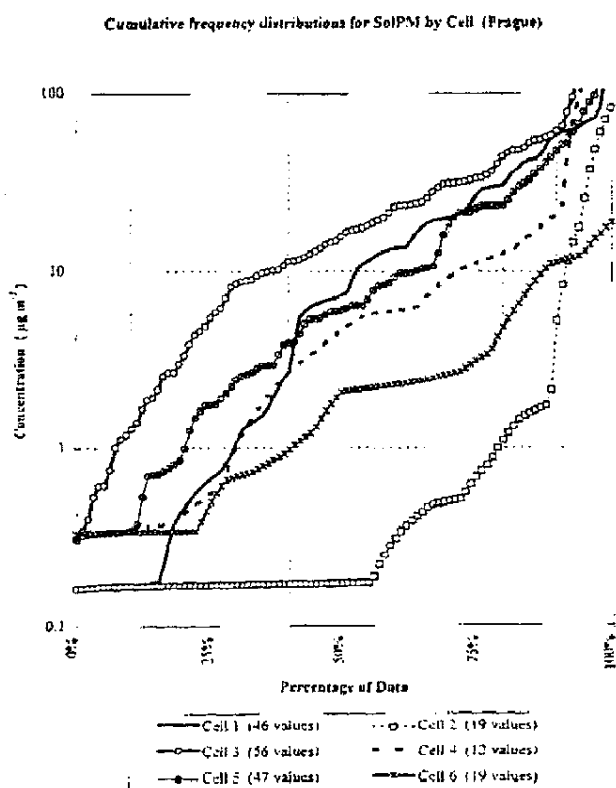

Fig. 3 Cumulative frequency distributions determined for SolPM by cell (Prague)

cantly higher ($P \leq 0.05$) than those noted for all other cells investigated and were directly comparable with the median levels of 18 $\mu g\ m^{-3}$ determined for subjects in Turin (Phillips et al, 1997b). The levels of ETS particles determined for workers living in nonsmoking homes and working in smoking workplaces (cell 5) were not significantly different ($P > 0.05$) from those determined for workers living in smoking households and working in nonsmoking workplaces (cell 4) or for housewives living in smoking households (cell 1). This would indicate that in Prague there was a significant contribution to overall ETS particle levels from the workplace where smoking takes place, since on average, less than 8 h of the 24-h period was spent in the workplace. The lowest median concentration of ETS particles (0.17 $\mu g\ m^{-3}$) was determined for housewives living in nonsmoking households, measured levels being significantly lower ($P \leq 0.01$) than those recorded for all other cells. The equivalent cell 2 concentrations for Barcelona, Basel, Paris and Turin were 1.0, 0.13, 0.52 and 0.47 $\mu g\ m^{-3}$ respectively. The median level of ETS particles determined for cell 6 (workers both living and working in nonsmoking environments, 2.1 $\mu g\ m^{-3}$) was the highest recorded for cell 6 subjects in any of the European cities investigated to date, possibly suggesting an indistinct segregation of smoking and nonsmoking workplaces in Prague. The highest median nicotine concentration (1.6 $\mu g\ m^{-3}$) was found for cell 3, with measured levels being significantly higher ($P \leq 0.01$) than those noted for all other cells. The highest median nicotine concentrations were also found for cell 3 subjects in Turin (1.3 $\mu g\ m^{-3}$), Paris (1.4 $\mu g\ m^{-3}$) and Basel (0.9 $\mu g\ m^{-3}$).

There was no significant difference ($P > 0.05$) between the levels measured for subjects in cells 1, 4 and 5, a pattern also mirrored by 3-EP concentrations, indicating that the impact upon 24-h TWA levels from the workplace was comparable with that of homes where smoking takes place. This reinforces the suggestion that there was a significant contribution to overall levels from the workplace where smoking takes place. The lowest median nicotine levels were recorded for cells 2 and 6 (0.15 and 0.16 μg m^{-3}, respectively), which comprised only nonsmoking environments. The levels determined for these cells were significantly lower ($P \leq 0.01$) than those recorded for all other cells investigated.

Saliva cotinine

Saliva cotinine concentrations, expressed as an average of pre- and post-monitoring levels, are reported by cell in Table 6. The levels determined for subjects either working or living in a smoking environment (cells 1, 3, 4 and 5) were significantly higher ($P \leq 0.001$) than those reported for subjects not usually exposed to smoking environments (cells 2 and 6). The highest median concentration was recorded for working subjects both living and working in smoking environments (2.4 ng ml^{-1}), measured levels for these subjects being significantly higher ($P \leq 0.001$) than those noted for all other cells with the exception of cell 4 ($P > 0.05$, 1.8 ng ml^{-1}). The lowest median levels were reported for housewives living in nonsmoking households ($< LOQ$) and for working subjects both living and working in nonsmoking environments ($< LOQ$). These findings indicate that there is a potential use for saliva cotinine measurements in the assessment of ETS exposure, provided that a method with a greatly improved LOQ can be used.

Potential inhaled quantities of RSP, ETS particles and nicotine

The term *exposure* is often used in the definition of maximum allowable concentrations for hazardous compounds and is normally determined by fixed site monitoring over standard periods. In the context of this personal monitoring study, where concentrations cannot be directly related to a specific environment, the term exposure was used as a measure of "potential inhaled quantity" (PIQ) and was calculated as the product of the analyte concentration, the length of time subjected to such concentration and the breathing rate maintained throughout the period. Exposures reported in terms of cigarette equivalents (CEs) were calculated in relation to the mainstream particle (tar) and nicotine yields of typical Czech cigarettes, although it is recognised that the particle phases of ETS and mainstream smoke differ considerably in composition and particle size. The values, 14 mg mainstream particles (tar) and 1 mg nicotine, were calculated as the mean yields of the six top selling cigarette brand-types in the Czech Republic. In this publication, CEs are used solely for conceptual comparison of exposure between groups of nonsmokers. In this context the factor used to relate the exposure of nonsmokers to smokers (Ogden and Martin 1997) was not required.

Daily exposures in terms of PIQs (in micrograms), calculated for each subject group (cell) over the 24-h monitoring period, are summarised in Table 7. The daily exposure for each subject was calculated using the concentrations and sampling times determined from their individual monitors and the assumed "awake" breathing rates of 0.65 m^3 h^{-1} for females and 1.05 m^3 h^{-1} for males (Holcomb 1993) for the entire 24-h monitoring period. Median and 90th percentile PIQs were subse-

Table 7 PIQs of RSP, ETS particles and nicotine as determined for all subjects during the 24-h monitoring period (Prague)[a]

Subject group[b]	RSP (μg)	ETS particles		Nicotine (μg)
		SolPM (μg)	FPM (μg)	
Median PIQ				
Cell 1	758	115	771	11
Cell 2	492	2.7	74	2.3
Cell 3	985	263	773	27
Cell 4	626	62	414	8.2
Cell 5	688	102	437	11
Cell 6	452	28	244	2.8
90th percentile PIQ				
Cell 1	1750	903	1612	51
Cell 2	867	82	1029	8.1
Cell 3	2227	1050	2077	86
Cell 4	807	509	803	88
Cell 5	1205	819	1187	34
Cell 6	1199	188	452	12

[a] A breathing rate of 0.65 m^3 h^{-1} was assumed for females, as was 1.05 m^3 h^{-1} for males. The exposure time was that recorded on the monitors worn by each subject
[b] Cell 1: smoking household, cell 2: nonsmoking household, cell 3: smoking household/smoking workplace, cell 4: smoking household/nonsmoking workplace, cell 5: nonsmoking household/smoking workplace, cell 6: nonsmoking household/nonsmoking workplace

quently calculated for each cell from these individually calculated daily PIQs to represent "typical" and "highly exposed" subjects, respectively.

The highest median daily exposures to RSP, ETS particles and nicotine were found for workers both living and working in smoking environments (cell 3). Median daily exposures of ETS particles recorded for these subjects (263 µg) were at least 3 times higher than those calculated for an equivalent group in a recent United States study (Jenkins et al. 1996) but were less than the median daily exposure of 370 µg measured in Turin (Phillips et al. 1997b) for cell 3 subjects. However, median RSP and nicotine exposures were comparable. For employed subjects living in smoking homes and working in nonsmoking workplaces (cell 4), ETS particle exposures were approximately 3 times higher than those found for equivalent United States subjects, but nicotine exposures were 25% lower in Prague. For cell 5 subjects (nonsmoking home, smoking workplace), median exposures to ETS particles (102 µg) were approximately 50 times higher and median nicotine (11 µg) exposures were approximately 4.5 times higher than those noted for equivalent subjects in the United States study. These

values noted for cell 5 in Prague were similar to those found in Turin at 60 µg for ETS particles and 8 µg for nicotine. These data would suggest that the workplace contribution to overall exposure in Prague is far greater than workplace contributions in the United States but is typical of values found across Europe by these authors. The least exposed subjects over the 24-h period as based upon median levels of ETS particles and nicotine were housewives from nonsmoking households (cell 2).

For the estimation of annual exposures, separate procedures were adopted for housewives and for workers. PIQs for each housewife were calculated by assuming that they were subjected to their measured concentrations for an entire year and that a breathing rate of $0.65\ m^3\ h^{-1}$ was maintained at all times. For cells 3–6 (workers), annual exposures for each subject were calculated from data provided by the separate monitors worn in the workplace and away from the workplace. Male and female working subjects were assumed to have breathing rates of 1.05 and $0.65\ m^3\ h^{-1}$, respectively, at all times and to spend 35 h per week and 48 weeks per year in the workplace. Annual exposure calculations for all subjects assumed no variation in ETS marker con-

Table 8 Annual PIQs of RSP, ETS particles and nicotine as determined for all subjects (Prague)[a]

Subject group[b]	PIQ (mg/y)				CE/y		
	RSP	ETS particles		Nicotine	SolPM	FPM	Nicotine
		SolPM	FPM				
Median PIQ							
Cell 1	275	42	278	4.1	3.0	20	4.1
Cell 2	179	0.99	27	0.84	0.07	1.9	0.84
Cell 3	349	92	308	9.5	7.0	22	10
Cell 4	218	19	116	2.6	1.4	8.3	2.6
Cell 5	235	29	146	3.2	2.1	10	3.2
Cell 6	156	12	77	1.1	0.84	5.5	1.1
All workers	272	36	172	4.2	2.6	12	4.2
90th percentile PIQ							
Cell 1	637	329	588	18	24	42	18
Cell 2	315	30	375	2.9	2.1	27	2.9
Cell 3	790	405	769	28	29	55	28
Cell 4	305	122	291	23	8.7	21	23
Cell 5	406	211	464	9.3	15	33	9.3
Cell 6	393	51	158	2.8	3.7	11	2.8
All workers	696	359	655	23	26	47	23

[a] Breathing rates of $0.65\ m^3\ h^{-1}$ for females and $1.05\ m^3\ h^{-1}$ for males were assumed. Annual PIQs for individuals in cells 1 and 2 were calculated by extrapolation of their calculated air concentrations to 1 year as follows:

Individual annual PIQ = air concentration × (0.65 or 1.05) × 24 × 365.

ETS marker concentrations for workers at work and outside the workplace were calculated from the data provided by the "work" and "home" monitors. Annual PIQs for individuals in cells 3–6 were calculated as follows, assuming a 35-h working week and 48-week working year with the remainder of the time spent outside the workplace:

Individual annual PIQ = "work" concentration × (0.65 or 1.05) × 35 × 48 + "home" concentration × (0.65 or 1.05)
× [(24 × 365) − (35 × 48)]

Median and 90th percentile data were calculated for each cell from the individual PIQs as determined above

[b] Cell 1: smoking household, cell 2: nonsmoking household, cell 3: smoking household/smoking workplace, cell 4: smoking household/nonsmoking workplace, cell 5: nonsmoking household/smoking workplace, cell 6: nonsmoking household/nonsmoking workplace, "All workers": cells 3–6 combined

Table 9 Estimated contribution of the workplace to annual exposure to RSP, ETS particles and nicotine for all working subjects (Prague)[a]

| Subject group[b] | RSP | ETS particles | | Nicotine |
		SolPM	FPM	
Cell 3	26% (16%)	39% (34%)	21% (18%)	38% (28%)
Cell 4	19% (10%)	23% (20%)	12% (11%)	30% (23%)
Cell 5	33% (18%)	65% (32%)	32% (25%)	56% (27%)
Cell 6	33% (24%)	55% (27%)	26% (20%)	45% (19%)
All workers	29% (18%)	49% (34%)	25% (21%)	45% (28%)

[a] Contributions are reported as the mean (standard deviation) of the percentage of annual potential inhaled quantity (PIQ) at work for all subjects. PIQs were calculated assuming that the measured concentrations from each individual subject's monitors were maintained throughout the year and that they spent 35 h per week and 48 weeks per year at work
[b] Cell 3: smoking household/smoking workplace, cell 4: smoking household/nonsmoking workplace, cell 5: nonsmoking household/smoking workplace, cell 6: nonsmoking household/nonsmoking workplace, "All workers": cells 3-6 combined

centrations throughout the year, including weekends, from those measured during the monitoring period. Median and 90th percentile exposures by cell, calculated from the estimated annual PIQs using the above-mentioned assumptions, are reported in Table 8 together with estimates for ETS and nicotine exposure in terms of CEs.

Ranking of cells by median values for annualised ETS particle and nicotine exposure shows cell 3 > cell 1 > cell 5 > cell 4 > cell 6 > cell 2. Median annual PIQs calculated for all workers (cells 3-6) were directly comparable with median PIQs calculated for housewives living in smoking households. It was also apparent that workers living in nonsmoking households and working in smoking workplaces (cell 5) had higher median annualised exposures to RSP, ETS particles and nicotine than did workers from smoking households working in nonsmoking workplaces (cell 4). Median annualised exposures determined for workers from cell 5 were also comparable with those determined for housewives living in smoking households (cell 1). This would suggest that a smoking workplace was a significant contributor to annual ETS exposure in Prague.

As based upon median levels of ETS particles (Sol-PM) and nicotine, no group (cell) would potentially

inhale more than 10 CEs per year (CE/y) and the least exposed, those subjects from entirely nonsmoking cells (2 and 6), would inhale approximately 1 CE/y. The most highly exposed (90th percentile levels) nonsmokers in this study, who both worked and lived with smokers, would potentially inhale between 28 (nicotine) and 29 (SolPM) CE/y. Conversely, if they came from nonsmoking households/workplaces they would inhale less than 4 CE/y. By applying the same criteria used for the calculations in Table 8, we could also estimate the contribution of the workplace to overall annualised exposures for each subject. A summary of these estimates, expressed as the mean percentage of contribution (standard deviation in parentheses) by cell, is presented in Table 9. Overall, the workplace would appear to contribute between 45% and 49% of the annual exposure to nicotine and ETS particles, respectively.

Concentrations of RSP, ETS particles, nicotine and 3-EP based on location

The concentrations of RSP, ETS particles and nicotine to which working subjects were exposed both inside and outside of the workplace were assessed using data pro-

Table 10 Concentrations of RSP and ETS markers as determined for working subjects in smoking environments (Prague)

Analyte	Environment	Number of subjects	10th percentile	90th percentile	Arithmetic mean	Geometric mean	Median
RSP	Work[a]	110	21	161	79	59	61
(μg m^{-3})	Home[b]	70	22	105	61	49	50
SolPM	Work[a]	109	0.51	106	44	12	15
(μg m^{-3})	Home[b]	70	0.27	58	25	4.9	5.9
FPM	Work[a]	109	6.8	136	57	32	35
(μg m^{-3})	Home[b]	69	9.9	130	58	39	44
UVPM	Work[a]	107	12	132	67	40	42
(μg m^{-3})	Home[b]	68	11	96	47	32	32
Nicotine	Work[a]	108	0.19	8.2	3.2	1.4	1.5
(μg m^{-3})	Home[b]	72	0.14	3.3	1.3	0.72	0.78
3-EP	Work[a]	109	0.15	3.0	1.4	0.67	0.76
(μg m^{-3})	Home[b]	71	0.08	1.4	0.69	0.41	0.46

[a] Data from the "workplace" monitor of subjects in cells 3 and 5
[b] Data from the "home" monitor of subjects in cells 3 and 4

Table 11 Concentrations of RSP and ETS markers as determined for working subjects in nonsmoking environments (Prague)

Analyte	Environment	Number of subjects	10th percentile	90th percentile	Arithmetic mean	Geometric mean	Median
RSP	Work[a]	32	12	78	93	36	34
$(\mu g\ m^{-3})$	Home[b]	67	12	55	32	25	27
SolPM	Work[a]	32	0.49	19	6.0	2.2	1.8
$(\mu g\ m^{-3})$	Home[b]	67	0.24	4.9	7.1	0.83	0.55
FPM	Work[a]	32	4.3	31	16	13	11
$(\mu g\ m^{-3})$	Home[b]	66	5.9	64	27	16	14
UVPM	Work[a]	32	8.9	40	22	18	17
$(\mu g\ m^{-3})$	Home[b]	66	8.1	32	20	15	14
Nicotine	Work[a]	32	0.15	1.3	0.90	0.41	0.35
$(\mu g\ m^{-3})$	Home[b]	66	0.06	0.42	0.43	0.16	0.13
3-EP	Work[a]	32	0.12	0.77	0.37	0.26	0.22
$(\mu g\ m^{-3})$	Home[b]	66	0.06	0.26	0.20	0.12	0.11

[a] Data from the "workplace" monitor of subjects in cells 4 and 6
[b] Data from the "home" monitor of subjects in cells 5 and 6

vided by the individual monitors. Individual monitor contributions were combined to provide an estimate of exposure concentrations in smoking (Table 10) and nonsmoking (Table 11) environments both inside and outside the workplace. Comparison of saliva cotinine levels was not meaningful using this procedure and these data were excluded from the tables. As indicated above, the expected trend of RSP > UVPM > FPM > SolPM was not observed at all concentrations and FPM levels were found to be elevated. From Table 10 the ratio of work/home for median SolPM is approximately 2.5, whereas for FPM and UVPM it is 0.8 and 1.3, respectively. This indicates higher levels of fluorescing compounds in the home as compared with the workplace. Our questionnaire survey indicated that 50-75% of all homes/offices measured in this study were heated by steam/hot water. It is possible that a higher percentage of communal housing used coal-fired heating systems as compared with workplaces, which may have used gas- or oil-fired systems.

When the smoking status of the environments was taken into account, median levels of RSP measured in the workplace ("work") were comparable with levels measured outside the workplace ("home"). However, median RSP levels were typically twice as high in locations where smoking regularly took place. ETS particle and nicotine concentrations detected in the workplace were between 2 and 3 times higher than those measured outside the workplace, and concentrations found in smoking locations were at least 4 times higher than the levels measured in equivalent nonsmoking locations.

Subjective comparisons of ETS exposure

As part of the last visit survey, subjects were asked a number of subjective questions regarding their exposure to ETS, both in general and during the 24-h monitoring period. The environments assessed by subjects as being the single location where they were exposed to the most

Table 12 Subjective assessment of the environment where subjects think they are exposed to the most tobacco smoke in the air (Prague)

Environment	Responses (%)[a]
Restaurants/bars	34.5
Home	14.3
Work	13.9
Outdoors	4.2
Other indoor locations	1.7
Traveling/driving	1.3
Nowhere/not exposed	1.3

[a] Responses were calculated as a percentage of total recruits; 69 subjects did not respond to this question or selected more than 1 environment

ETS are listed in Table 12. This table shows that almost equivalent percentages of subjects chose the workplace as compared with the home as the location where their highest exposure to ETS took place. The location generally perceived to contribute most to ETS exposure were restaurant or bar areas.

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